Traffic Light System

I apologize in advance for stating the obvious, but I wanted to write all this down to get things clear in my own head and thought I would pass it on to the group. As Jeff Bull stated in an earlier email, our objective is to develop a frame work from which a stop light system could be put in place should one want to (operator or regulator). Before going too far, I wanted to put down a few basic beliefs that I worked from when drafting this document:

- I have been very impressed by the extent and depth of analysis that has been brought to bear on Induced Seismicity (IS) from all sectors. From not a lot of data points, a clearer understanding of the issues now exists.
- I used M_L (Richter Magnitude)for all thresholds, my reasoning is that all other measurements can be calculated from this value, it is a good base reference for everyone, and it is a value that is understood by the general population.
- We are here to find a workflow that addresses IS from a scientific perspective, but strikes a balance between Public Policy and Science. Because the vast majority of stakeholders in this process are non-technical (at least in an earth science perspective), we must be clear and simple in describing whatever process we agree upon.
- As many have pointed out, each play varies in seismicity, and no one workflow will cover all areas, however, all traffic light systems require conditions and thresholds for each level (green, amber, red) and each level has basic requirements that cover all areas. Thresholds and level requirements may vary but the framework, particularly for the green and red levels, are transferable to most all areas.
- In my opinion, there are two venues to apply the traffic light system, spatially and temporally. In simplest form the spatial system would be a map with areas designated as green, amber, and red. The temporal system would be the steps in place during the operation of a disposal well or while a well is being completed.
- For the purpose of this document I am running with the assumption that $M_L \leq 2.0$ is below the human perceptible range and $M_L \geq 4.0$ is the threshold for the red light. These thresholds should be adjusted for different areas.
- I believe the general consensus is that, although there are plenty new examples of IS data, the problem is not well understood and more study and data are required.
- Injection volumes seem to be a driver of EQ magnitude
- For the purpose of this document, I do not distinguish between seismicity induced by water injection or well completion although in my opinion I believe they are separate but related.

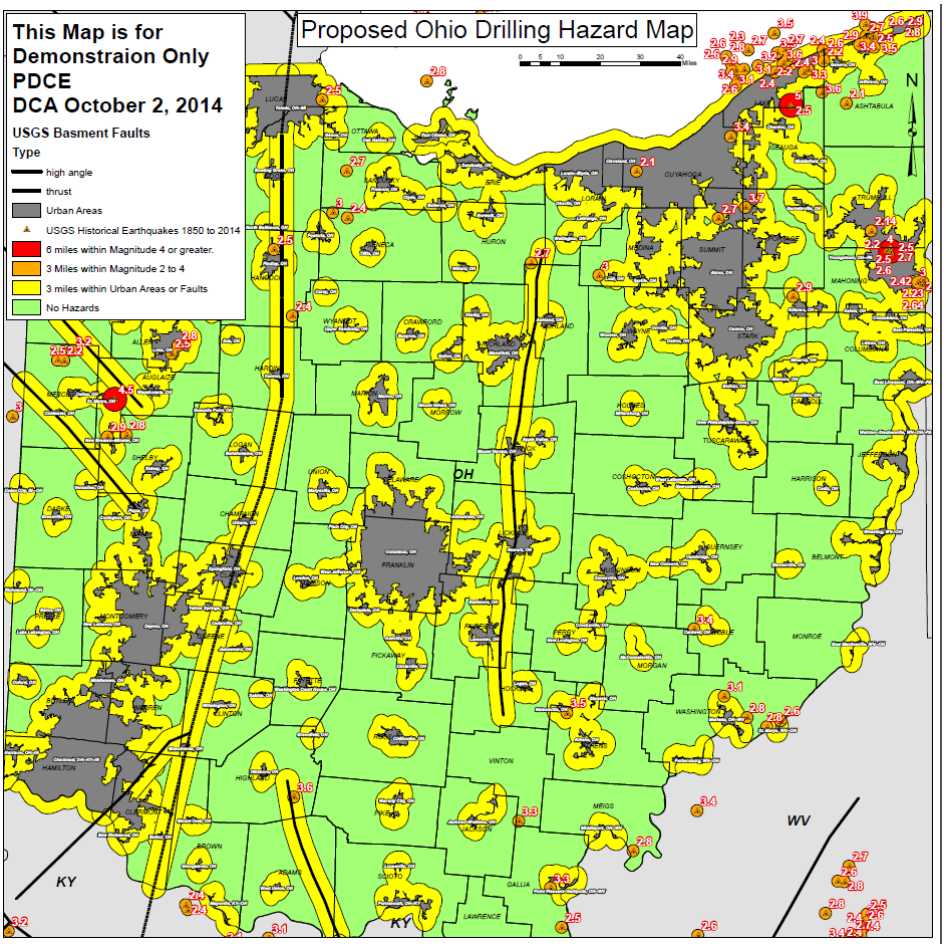
Spatial Traffic Light System (STLS)

Arkansas has a moratorium on disposal wells in the area surround Guy, Arkansas. Colorado is evaluating increased requirement for any disposal well within a 2.5 miles radius of the epicenter of seismicity greater than M_L 2.5. Ohio is requiring monitoring in areas near within 3 miles of known faults or Earthquakes of $M_L \geq 2.0$. Oklahoma has established Critical Areas which relate to 6 miles from and EQ of Mag 4.0+.

IF you try to consolidate these limits to a single set of criteria, the result is a map of three levels which work requirements differ (see the map below which is for demonstration purposes only). Red – an example is the Arkansas moratorium and Oklahoma's Critical Areas, Amber – examples are Colorado's 2.5 mile radius from a 2.5+ magnitude EQ, or Ohio's 3 mile zone from known faults or EQ of Mag 2 or larger. Green would cover all other areas.

Criteria in defining the areas of different levels should consider, but not necessarily be limited to – previous earthquake activity, population centers, and active faults. Possible other map influencers – previous injection activity, areas of large injection volumes.

In red areas, there would be no operations, in green areas, operations would proceed has they had prior to the IS occurrences. Amber areas would have site specific requirements on a case by case basis. The permit application for operations would have to detail a mitigation plan to eliminate or minimize IS during activity. Monitoring would be required at a level acceptable by the regulatory authority. A step by step plan would be required in case seismic events above stated green levels occurred. Operations are shut down if red levels are exceeded – The events leading up to the EQ will be investigated and further operations will only continue if deemed safe to do so.



The previous map is a possible example STLS map for Ohio using the criteria shown in the legend. The faults are from a Trenton Black river study and are used for this sample. This map is an example only and is meant to demonstrate what such a map could look like. This should be a living document that adds detail as more data become available. For example if it is found one of the "known faults" is inactive or is oriented with respect to regionial stress so it is very unlikely the fault would cause a seismic event, then it can be removed from the map, conversely if a active fault is discovered, it should be added.

Temporal Traffic Light System (TTLS)

A temporal Traffic light system is site specific and relates to completion of injection operations. Operations will be contingent on where the operations will take place with respect to the Spatial Traffic Light System – depending upon what level the operations fall in - additional monitoring, injection procedures, and threshold limits (or other requirements) may be in place.

It is easy to get consensus on the simplicity of the green and red levels. In the green level, there are no additional restrictions, in the red level, there are no operations. The thresholds are subject to much debate, but generally, everyone agrees that the upper limit of the green level should be at a magnitude that is just at or slightly below what can be felt. The red level should be at the maximum level where no damage occurs.

Since the red and green levels are almost entirely dependent on the threshold at which the levels are defined, the focus in the TTLS will be on the amber level. The restrictions on operations and the monitoring requirements should be permit requirements but should mean additional monitoring and a action plan on operations that address the procedures in place if activity exceeds green levels and mitigating actions as seismicity increases.

A very good example of a TTLS, albeit for a CCS project, is provided in the link below provided by Bill Bates from the EPA.

Injection wells vs. Well completions

In the United States there are very few incidents of hydraulic fracturing inducing seismicity, and some of those cases may have some influence by injection activity near the fracturing events. Regardless, most of the earthquakes linked to hydraulic fracturing in the US are low in magnitude (less than M_L of 3). In my previously stated opinion, Injection wells and well completions should be treated separately as they induce seismicity differently. Completion efforts cannot produce enough force to induce a seismic event unless energy is "borrowed" from another source – be that regional stress, injection pressure from neighboring injection wells, or some other source.

Transitioning Levels

The mounting data allows for more accurate mapping over time and as mentioned above, the STLS mapping should be a living document that becomes more accurate with increasing input. Areas that are originally green may eventually fall into the amber or red levels, similarly, over time amber areas may

eventually change to green if, over time, no seismicity occurs. Or maybe, amber turns red if seismicity increases.

During TTLS, if operations that have seismicity that creeps into the amber level, the mitigation plan presented during the permit process, is implemented and the seismicity should fall back into the green level. A previously green area turns red (using the criteria shown above) if seismic events of $M_L \geq 4$ occurs.

Other considerations

Since the phenomenon of induced seismicity is currently not fully understood, level descriptions and mitigations steps should take this into consideration and should apply the best practices according to the current understanding of IS drivers – with the knowledge that this understanding is going to change over time.

A monitoring system needs to be in place to locate IS events within a certain level of accuracy (that needs to be determined). Kansas, Oklahoma, and Ohio are evaluating such networks. Who monitors the system, how the cost of such a network is covered, the spacing, number and type of monitoring need to be agreed upon. Another discussion is to determine if the network is necessary if additional monitoring is required in the amber and red areas. If additional monitoring is required in the areas of amber and red levels, then the accuracy and ground motion detectability need to be determined. Or if a combination of the two systems is to be used, how do they work in concert?

More study or more experience is needed in determining the mitigation steps in the amber level. Shutting in may not be the proper action. Skipping stages (during completion) dropping rate, cycling activities are other means of mitigation and the proper means will be found over time.

Links

http://www.epa.gov/region5/water/uic/adm/pdfs/adm-ccs2-attachment-f-emergency-and-remedial-response-plan-201404.pdf

http://www.occ.state.ok.us/SEISMIC%20STATEMENT-a.pdf

http://www.ohio.com/blogs/drilling/ohio-utica-shale-1.291290/harrison-county-hit-by-positive-magnitude-fracking-quakes-in-2013-1.513784

http://kcc.ks.gov/induced_seismicity/seismic_action_plan_9_26_14.pdf

http://www.ogs.ou.edu/MEETINGS/Presentations/MSARB12/HOLLANDKELLER.pdf

http://www.aogc.state.ar.us/notices/Ex.%201B%20-Permanent%20Disposal%20Well%20Moratorium%20Area.pdf

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